Paper number: #188

Title:

Functional impacts of network-centric operations on Future C2

Author and point of contact:
Lorraine Dodd, Command and Intelligence Systems, Room 222 Alan Turing Building, QinetiQ, St Andrews Rd, Malvern, Worcs WR14 3PS, UK
Telephone: **(+44) 1684 896135**
Fax: **(+44) 1684 896767**
email: Ldodd@QinetiQ.com

co-authors:
Lt Col Merfyn Lloyd, Defence Science and Technology Laboratory [Dstl], N Building, St Andrews Rd, Malvern WR14 3PS, UK
email: **malloyd@dstl.gov.uk**

Geoff Markham, Command and Intelligence Systems, Room 208 Alan Turing Building, QinetiQ, St Andrews Rd, Malvern, Worcs WR14 3PS, UK
Telephone: **(+44) 1684 896399**
email: **gmarkham@QinetiQ.com**

Abstract for:

2005 10th International Command and Control Research & Technology Symposium

McLean, Virginia. June 2005.

Submitted for streams: Policy / Edge Organisations

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 2005		**00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Functional impacts of network-centric operations on Future C2	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **QinetiQ,Command and Intelligence Systems,St Andrews Road, Malvern,Worcester WR14 3PS, UK, ,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**		**31**	

Functional impacts of Network-Centric Operations on Future C2

Abstract

What are the unavoidable functional impacts of effects-based, network-centric operations (EBNCO) on command and control (C2)? In other words what C2 mechanisms, network structures and new ways of working are necessary to enable military forces to function in future conflict operations?

The central question is: what form(s) must the C2 organisations adopt to conform to the whole range of potential operational requirements? These requirements must cover, for example, the political need for accuracy and the likelihood of achieving precision due to the nature of the environment, number of interactions, rate of representative events and predictability. The effects-based nature of operations forces us to think of operational requirements in themselves rather than using pre-defined means as surrogate operational requirements. The desired effects drive the outcome objectives; and hence drive the plans, actions and inter-organisations of activities from which the C2 plan must naturally emerge.

How can we evaluate and assess capabilities in the context of a command space that has a lay-down of cost-benefit contours that define “OK regions” (or comfort zones or basins of attraction) for C2 organisations given a range of operational contexts? Perrow’s Quadrants help to define the command space within which the OK regions for the Way of Command can be defined.

INTRODUCTION

The Danish Chief of Defence in his plenary address at ICCRTS 2004 described a shift in the way that military operations have recently been planned and conducted. The shift has been away from starting with pre-defined MEANS to determine WAYS to achieve ENDS towards starting with defined ENDS then developing WAYS to make more of the MEANS. The shift in operational analysis (OA) methods provides a useful analogy as OA moves away from Linear Programming formulations with single criteria linear objective functions, well-defined variables providing single-agency constraints and feasible regions towards evolutionary methods within complex adaptive systems. There is a big problem, however. There is no methodology for generation of representative data and there are no useful structural methods for encoding capability options and hence it is difficult to define fitness measures and value landscapes[1]. This same problem applies to C2 effectiveness assessment now that agility, responsiveness and adaptability are the main drivers.

The central question is: what form(s) must the C2 (and supporting information) network(s) adopt to conform to the whole range of potential operational requirements? (These requirements must cover, for example, the political need for accuracy and the likelihood of achieving precision due to the nature of the environment, number of interactions, rate of representative events and predictability, in general.) The effects-based nature of operations forces us to think of operational requirements in themselves rather than using pre-defined means as surrogate operational requirements. The desired effects drive the outcome objectives; and hence drive the plans, actions and inter-organisations of activities from which the C2 plan must naturally emerge.

So it is important to characterise and fully acknowledge the extent and range of settings within which the EBNCOs may be situated; in particular, being explicit about the nature of the desired ends. What are the key features of the situation "command space" and what implications do these features have for determination of future Ways of Command? How can we evaluate and assess capabilities in the context of this command space such that it has a lay-down of cost-benefit contours that define OK regions or comfort zones or basins of attraction for C2 organisations given the above context?

Under these conditions, how can the mission objectives and the contribution of the assets and resources which may be at the Commander's disposal, be characterised? There is an 'inner' and an 'outer' problem here: the 'inner' problem considers how a specific military objective may be pursued with a declared range of assets and resources, whilst the 'outer' problem seeks to drive the acquisition of capability through an appreciation of the value of potential capabilities across an ensemble of settings within which the EBNCOs may be situated.

This paper is concerned with the 'inner' problem, whose resolution is clearly a pre-requisite for addressing the 'outer' problem of capability management. The 'inner' problem requires an explicit characterisation of the nature of the desired ends, and a sensitivity analysis in respect to asset / resource portfolios.

Perrow's Quadrants[2] help to define the command space within which the "OK regions" for the Ways of Command (and supporting infrastructures) can be defined.

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[1] Anne-Marie Grisogono, 'A generic framework for generating and exploring C2 concepts', 9 ICCRTS 2004.
[2] Charles Perrow. Discussed in 'Coping with the Bounds – speculations on Nonlinearity in Military Affairs'. Tom Czerwinski, Department of Defense Command and Control Research Program (CCRP), 1998 /2003.

COMPLEX ADAPTIVE SYSTEMS

There is a considerable literature on complex adaptive systems, of which the work of Perrow[3] provides indicators which are pertinent to the command problem. Perrow characterises systems in terms of the complexity of interactions with which they have to deal[4] and the coupling, which he describes as "the amount of slack, buffer or give between two items". Perrow then constructs four quadrants, as shown in Figure 1.

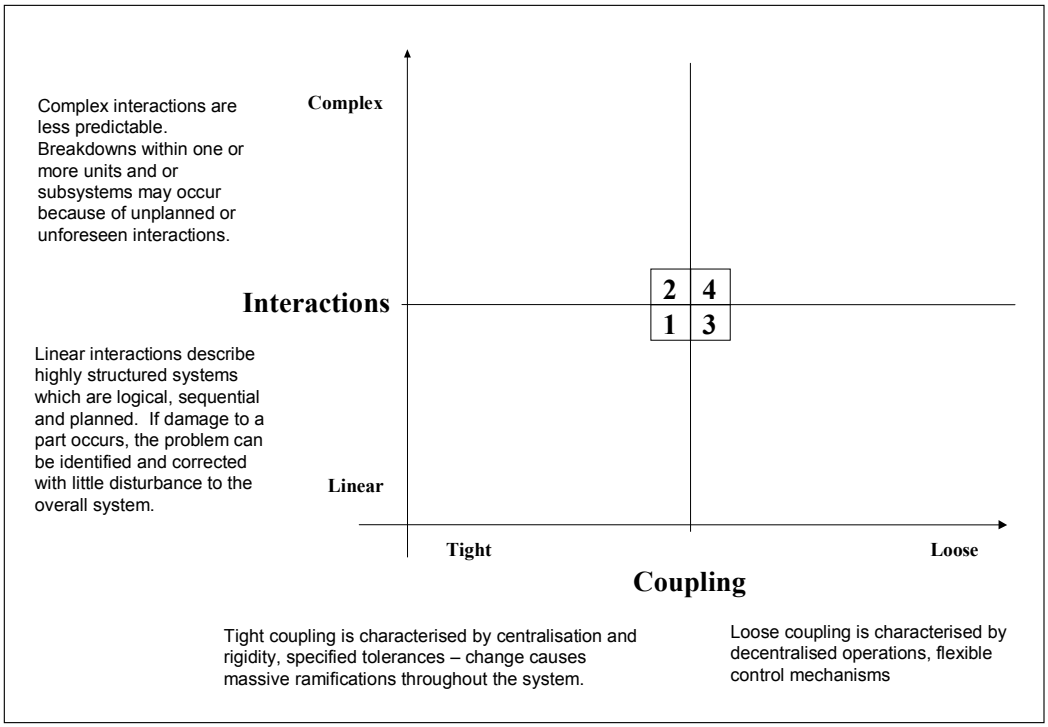

Figure 1: Perrow's quadrants

In each of the quadrants in Figure 1, Perrow then identifies whether a centralised or decentralised style of management is most appropriate (Figure 2) .

[3] Charles Perrow 'Normal Accidents: Living with High Risk Technologies' Basic Books Inc, New York 1984.
[4] Perrow considers interactions through the system itself; in the military case, it must be borne in mind that interactions can occur in the real-world adversarial environment within which the military system is embedded.

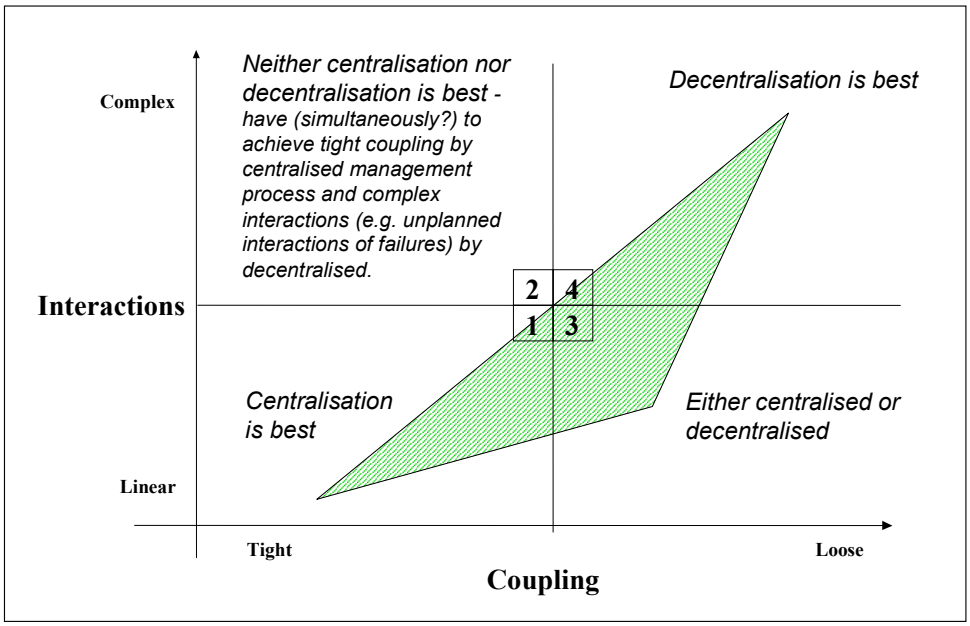

Figure 2: Management styles

Implicit in Perrow's assertions are that centralised management structures (which may be equated to 'low command freedom' approaches in the military context) cannot cope with complex interactions (Figure 3).

Hence, if the complexity of interactions is viewed as an independent variable (i.e. inherent in the military situation), the commander should be moving the style of inter-working of his organization (or at least specific parts of it) to Quadrant 4 (loose-coupled, high command freedom), as shown in Figure 4.

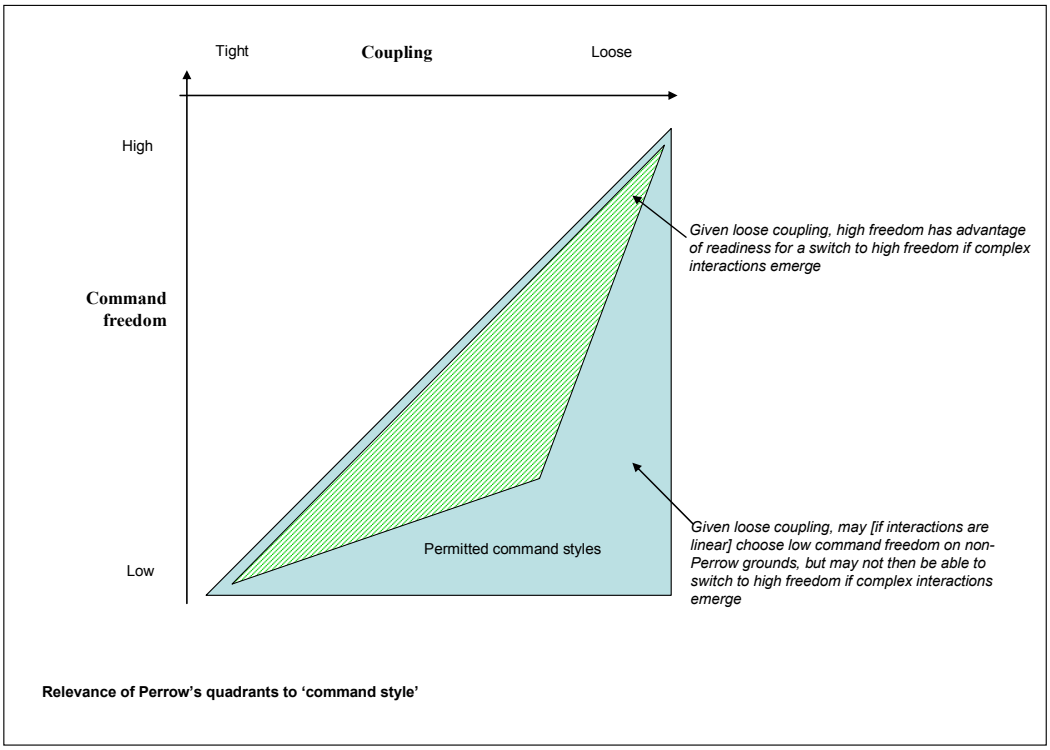

Figure 3: Implications of Perrow's quadrants for command freedom

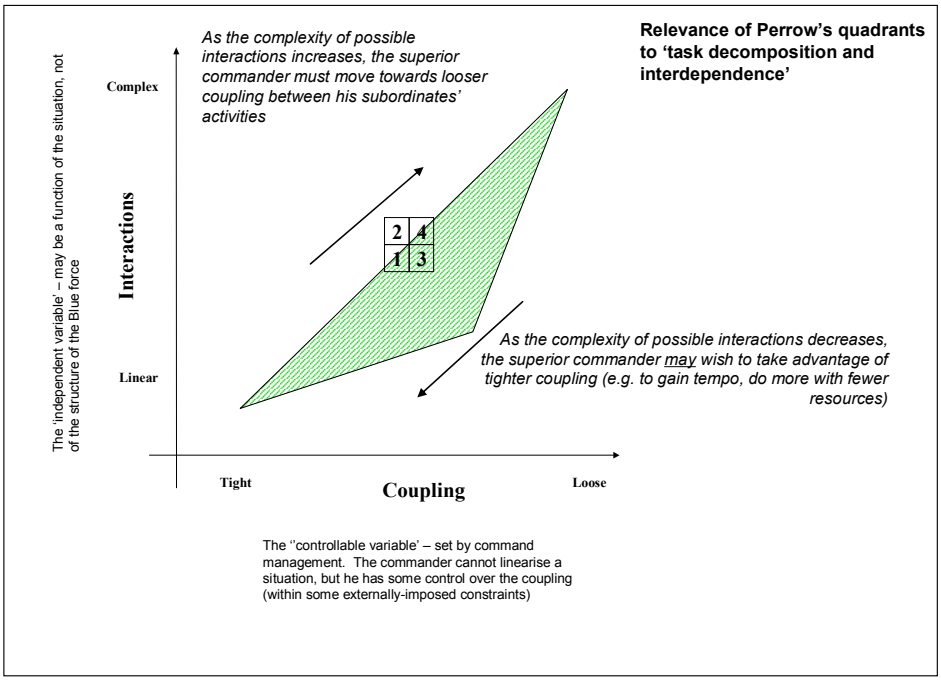

Figure 4: Commander's response to rising interaction complexity

Why can we not operate continuously in the loose-coupled, high command-freedom area (Quadrants 3 and 4)? There are drivers such as need for accuracy and resource limitations which call for tight coupling (requiring the selective reduction, at least, of command freedoms); there are particular operational activities (e.g. those involved in Air Manoeuvre) where tight coupling may be necessary to maintain the linearity inherent in the concept of operations. This gives rise to the notion not of an optimal coupling / interaction point in the command space but of mobility around a command space (Figure 5) such that the commander can define, dynamically, where he wants to operate for particular phases and mission types, trading command freedoms to work within other constraints.

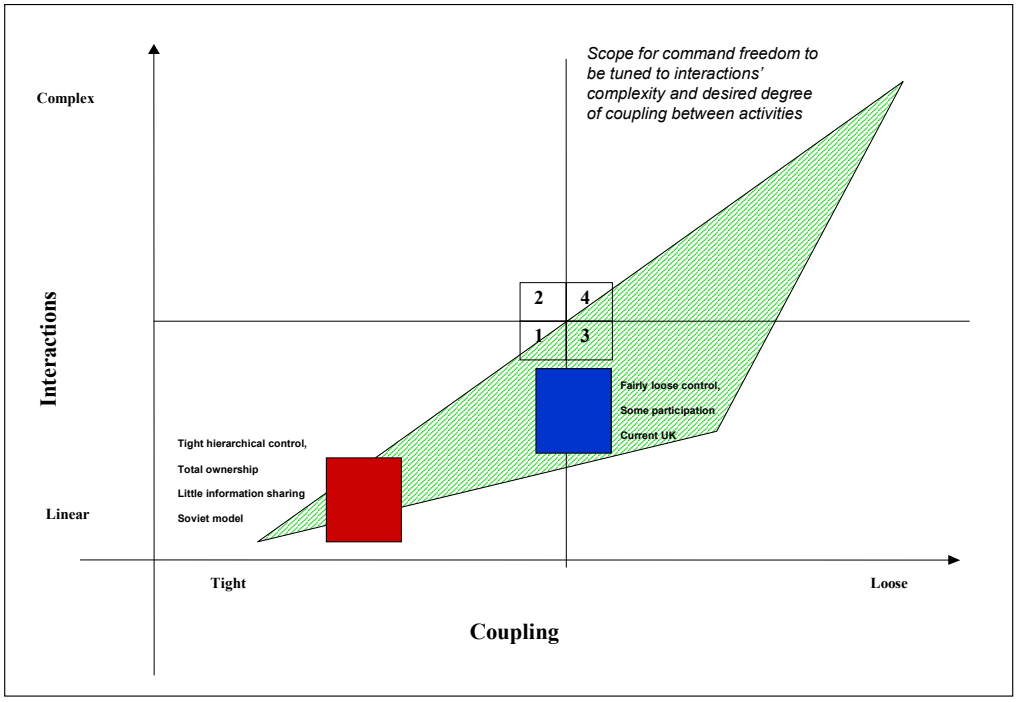

Figure 5: Operating in a command space – ability for command freedom to be tuned to interactions' complexity and desired degree of coupling between activities

The red box in the bottom left-hand corner of Figure 5 is indicative of a hierarchical organisation, mechanistic and highly procedural with little need to share information as tactical actions are already hard-wired by doctrine. The blue box is a representation of current UK land force organization. Top right of the diagram is where unconstrained 'Edge' organisations would be able to operate, having complete freedom to act in any way using any resource. The numbered quadrants are those described by Perrow and the green shading represents a general "OK" region of feasibility and sustainability.
As noted earlier, interactions can occur both within the military endeavour and within the environment or world-system within which it is located. Perrow's quadrants are a projection of three dimensions on to two: the two dimensions which have been merged to reflect the complexity of the military endeavour and of the world system respectively. The

commander needs to be thinking about both dimensions, but they may not match (i.e. it is not always appropriate to fight chaos with chaos).

THE COMMAND SPACE AND VALUE QUANTIFICATION

Perrow's Quadrants help to define the command space within which the "OK regions" for the Ways of Command (and supporting CIS structures) can be defined. But what are the key features of the situation "command space" and what implications do these features have for determination of future Ways of Command? How can we evaluate and assess capabilities in the context of this command space such that it has a lay-down of cost-benefit contours that define OK regions (or comfort zones or basins of attraction) for C2 organisations given the above context?

In order to make progress, we posit a military organization in which there are recognisable functional capabilities, and where networking, in the widest socio-technical sense, provides a way in which military components can gain access to a wider range of functionality. Integrating like-functions across the components of military capability, as expressed by these stable, utilitarian operational groupings, results in a defined set of functional integrations through which resources can be shared and requisite variety (in particular for C2 functions) found, as illustrated in Figure 6.

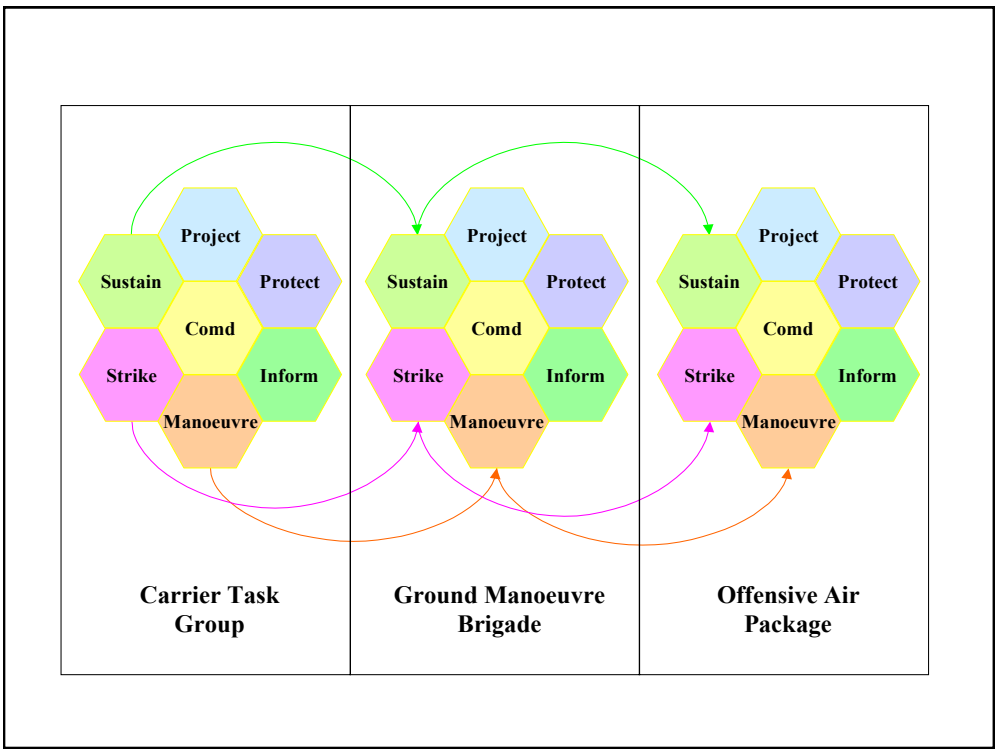

Figure 6: Functional Integration

This is the approach to Agile Mission Grouping pursued in the UK's proposed Capability Architecture 2020[5]. Broadening access to functionality across the groups is in effect a form of out-sourcing functionality and this can be valued in terms of responsiveness and

[5] M Lloyd, G Markham, L Dodd, M Saunders, 'Delivering Network Enabled Capability: a Capability Architecture for 2020', Dstl report TR12998 February 2005.

availability (see below). In the military context, completely out-sourcing the 'strike' function, for example, is at one end of a spectrum of sharing functionality, where the opposite extreme is complete (organic) ownership. This notion of a spectrum of participation and membership is important in considering what agile mission grouping means, how it might be achieved and the associated costs and risks.

Provision of infrastructures (both communications linkage and CIS) physically and logically networks together military components such that it should make available a wider range of functionality to any particular component through a concept of 'service provision'. Services are essentially distinguished from asset allocation (e.g. TASKORGs) by being open to dynamic invocation, representing an expedited commitment to the resources needed to execute a given mission.

The ability and extent to which resources can be shared rests on having clear lines of ownership, authority, permissions, responsibilities, etc and the mechanisms to allow efficient and effective negotiation and re-prioritisation. This aspect of shared situation understanding is, therefore, of prime importance to commanders at all levels but is often neglected in favour of provision of data and information networks. The ensuing discussion, therefore, describes how out-sourcing can be valued, how this is affected by the manner in which command is exercised, the C2 organisation chosen to implement it, and the functional implications that result.

THE VALUE OF OUT-SOURCING

The term 'out-sourcing' is used here because, in one respect at least, the process reflects similar behaviour to that employed in the commercial world. Coase's Law[6] suggests that out-sourcing occurs when networking makes the cost of ownership more expensive than out-sourcing. In its purest form, this assumes that the commoditisation of the product or service is such that it makes any provision of equal value, and, as such, cost is the only determining factor. In the military context, the value associated with out-sourcing a function (e.g. 'Strike') may depend heavily on the means of its provision (as there will be real issues of assured support and requisite responsiveness).

Figure 7 shows the structure of the value / cost assessment for increasing functional participation, relative to the value and cost of providing the capability from 'organic' elements. At this stage, the only aspect of value identified is a measure of the potential contribution to the military effectiveness, modulated by 'quality' of service measures. This can be represented indicatively as follows:

$$Value_1 = I\ Contribution\ I * f_1 (\ responsiveness, availability, predictability\ ).$$

The terms responsiveness, availability and predictability are (in this context) technical performance measures. Note that predictability – even knowing what resources you *cannot* get hold of – is always of some incremental value to the commander; and having an abundance of organic capability scores highly on predictability[7].

[6] Ronald Coase asserts that companies will expand until 'the costs of organising an extra transaction within the firm become equal to the costs of carrying out the same transaction on the open market'. Quoted in 'Outsourcing the IT Infrastructure', Paul A Straussman, Computer World, 12 January 2004. First published in 'The Nature of the Firm' in Readings in Price Theory, ed Stigler and Boulding, Irwin, Chicago, 1952.

[7] The definition of $Value_1$ ignores broader aspects of predictability (e.g. predictability of combined impact of military activities on the world system with which it is engaged, predictability of outcome); these aspects are more difficult to evaluate, and indeed the value of predictability in these dimensions is highly context-dependent.

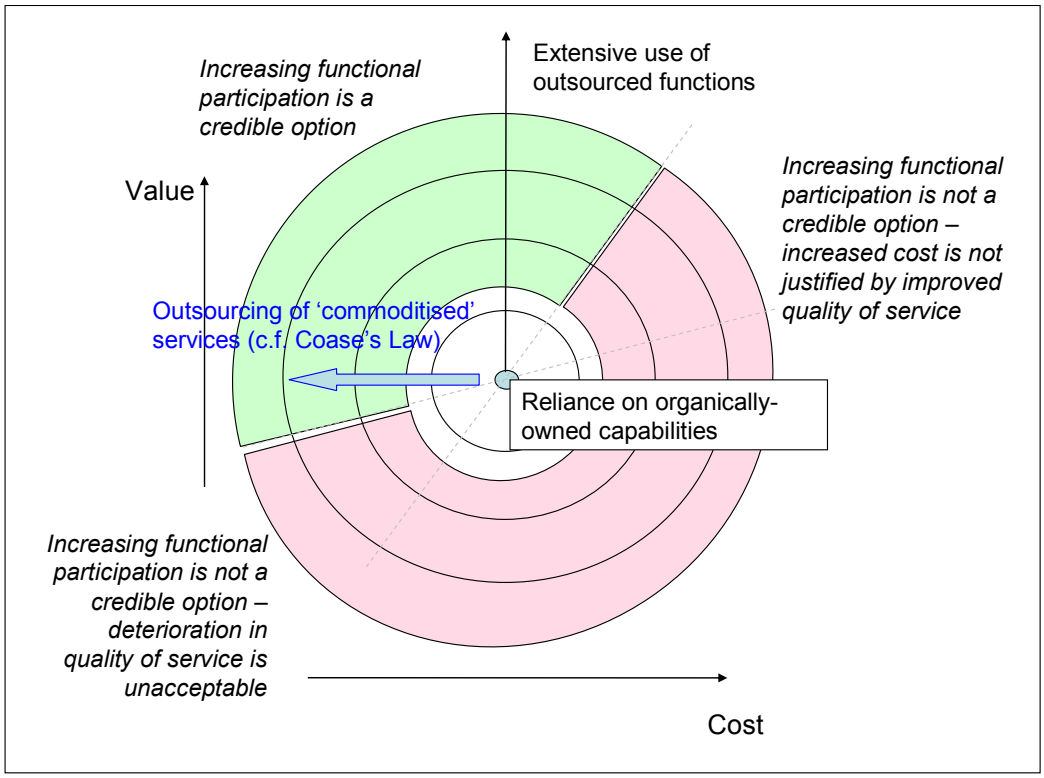

Figure 7: Value / cost assessment for functional participation options

There are additional considerations which impact upon the value of out-sourcing. For a start, a military organization places a strong value on there being clear lines of authority and accountability for actions performed (and not performed), and it is clear that these are dependent on the command arrangements which are in place. Hence the 'technical' quality of service measure ($Value_1$) may need to be modified by an assessment of the clarity and suitability of lines of authority, responsibility and accountability ($Value_2$).

IMPACT OF OUT-SOURCING ON THE COMMAND SPACE

Intuitively, networking appears to offer an increasing range of capabilities to the commander and hence should help to reinforce the degrees of autonomy which may be exercised in loose-coupled organizations. So, is functional participation (as characterised in Figure 7) always an enabler of command space agility? Figure 8 suggests that this is not always the case.

Impact of co-operative interworking between functions

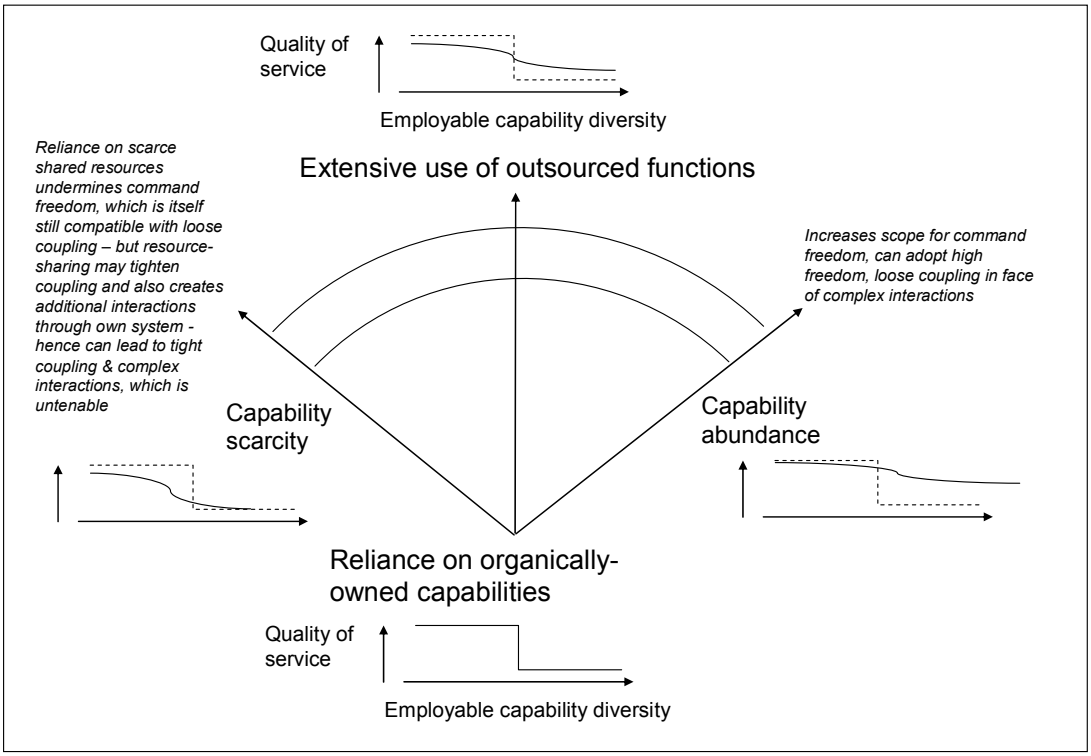

Figure 8: Effects of scarcity or abundance of resources

The iconic representations of quality of service versus capability diversity in Figure 8 attempt to contrast the situation where the only capability available is that which has been directly Task Organised into the force grouping in question (represented by the 'square wave') and the provision of services from capability-holding structures which are external to the force grouping in question (the 'cosine waves').

Figure 8 seeks to make the point that the impact of outsourcing is dependent on whether capabilities are (relatively) scarce or abundant. Of course, the primary impact of this is on responsiveness and availability (so it will show up in $Value_1$, as discussed at Figure 7). But also:

- If resources are abundant, the wider range of capabilities available to the commander reinforces his command freedoms and his autonomy of action within a loosely-coupled regime (as per Figure 3).
- If resources are scarce, this undermines the commander's ostensible freedom. This is not of itself incompatible with loose coupling, but the problem is that resource-sharing may tighten this coupling and may also create additional interactions through the military system itself (i.e. number of interactions is now a *dependent* variable).

The standard military response to a scarcity of resources or assets is prioritisation. However, a platform or asset cannot itself set the priority, it can only accept, reject or delay tasks. Priorities have to be set, and priority-handling mechanisms identified, by a commander with sufficient visibility and understanding of the problem. The more scarce the asset, the greater the tendency is to hold this at a higher level of command, thereby tightening the organisational coupling through the created dependencies.

The result of capability scarcity is to modify Figure 5 as shown in Figure 9.

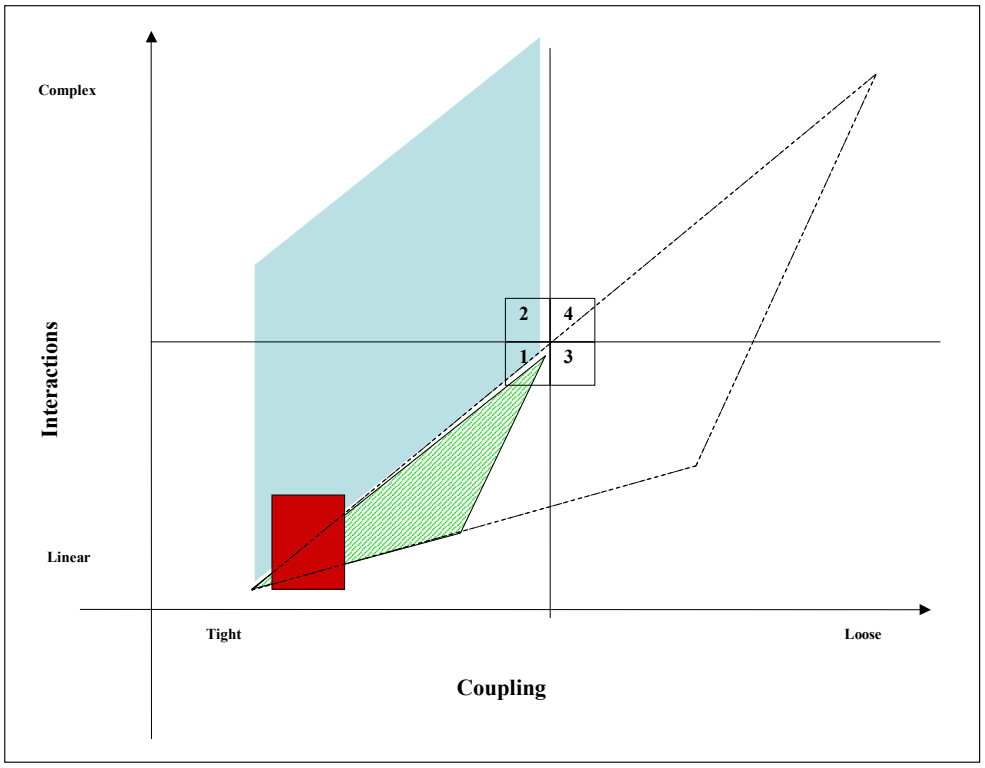

Figure 9: Effects of capability scarcity on command space

The patterned space in Figure 9 indicates the truncated command space. The blue-shaded portion reflects the vulnerability of the system to be driven into Quadrant 2 (tight coupling and complex interactions), which is difficult (and potentially dangerous) to sustain.

Thus, an efficient and robust solution will inevitably be a compromise between organic resourcing and functional out-sourcing. There are then three basic aspects of value that contribute to the cost-benefit contours of the "value landscape":

$Value_1$ = I Contribution I * f_1 (responsiveness, availability, predictability).
$Value_2 = f_2$ (authority, responsibility, accountability)
$Value_3 = f_3$ (command space mobility).

THE COMMAND SPACE AND THE COMMAND CHAIN

The command space within which the commander operates has to be managed for every commander in the command space (and introduces the notion of a Command Plan in addition to the other three HQ plans: Fire&Movement, Sustainment, Info.Collection). Figure 10 provides a compact representation of command arrangements that encompasses the functional range of C2 organisations.

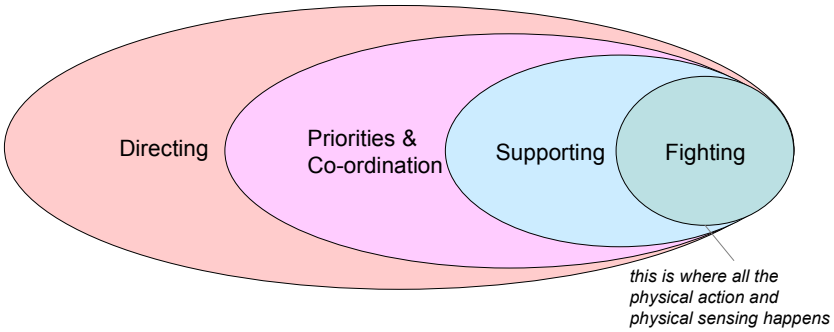

Figure 10. A simple representation of command arrangements

One paradigm for Figure 10 is where the supported commander is the Fighting Commander (i.e. he commands men and platforms in the essential physical action in combat). However, the Figure 10 model is recursive, and the Fighting Commander may be at a lower level (Figure 11).

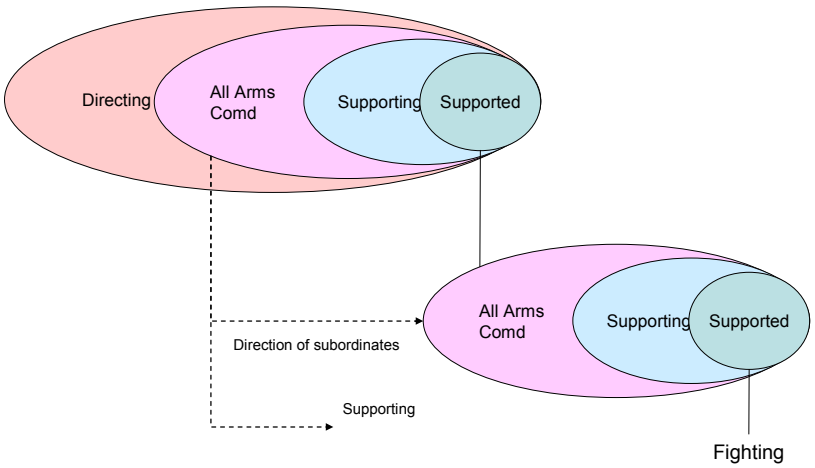

Figure 11: Recursive version of the command chain model

Each commander has a particular Zone of Responsibility (in terms of the portion of the world-system within which he has responsibility), so each of the four elements in the command chain model can be plotted according to Perrow (Figure 12).

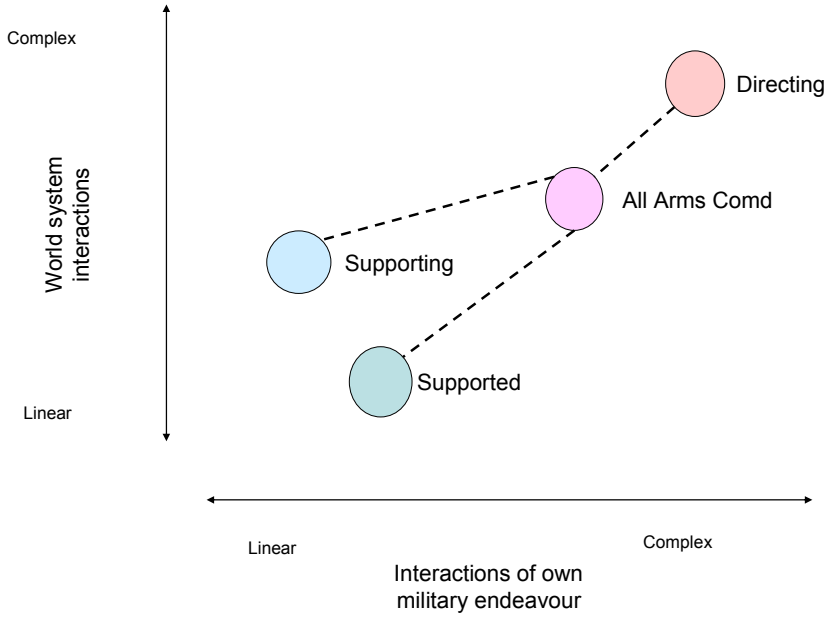

Figure 12: The command chain in the context of the interactions

The operation should be planned with a view to the pattern made by the four elements. The burdens of complexity and nonlinearity need to be allocated sensibly; it may be necessary, for example, for the All Arms Comd to maintain buffers and margins in order to linearise the tasks he gives to his subordinates. However, it is never enough to

consider only our own interactions. The nature of the enemy interactions as part of the "world system" must also be superimposed. Figure 13 shows this, using an extended three-dimensional view of the Perrow-based command space.

In general for a system to be able to adapt, survive and evolve, it must contain sufficient resources and C2 variety for the emergence of a viable solution to be a reasonable probability. Applied to military capability, this means that reducing functionality in one component on the grounds of substitution or out-sourcing from another will affect a force's ability to adapt to rapidly changing circumstances. The burdens of complexity and nonlinearity need to be allocated sensibly; it may be necessary, for example, for the Multi-Functional Supporting Command to maintain 'buffers' and margins. This is especially true if the only option is linearisation of the tasks given to subordinates (e.g. to enable tightly-coupled, coordinated activities in pursuit of high tempo and accuracy). Maintaining a functional 'buffer' across the components is important in delivering C2 agility and is a key measure of force robustness[8] but this has to be balanced to against the costs of buffer management. The key then to the inevitable problem of risk management is provision of networks and C2 organisations that enable anticipation.

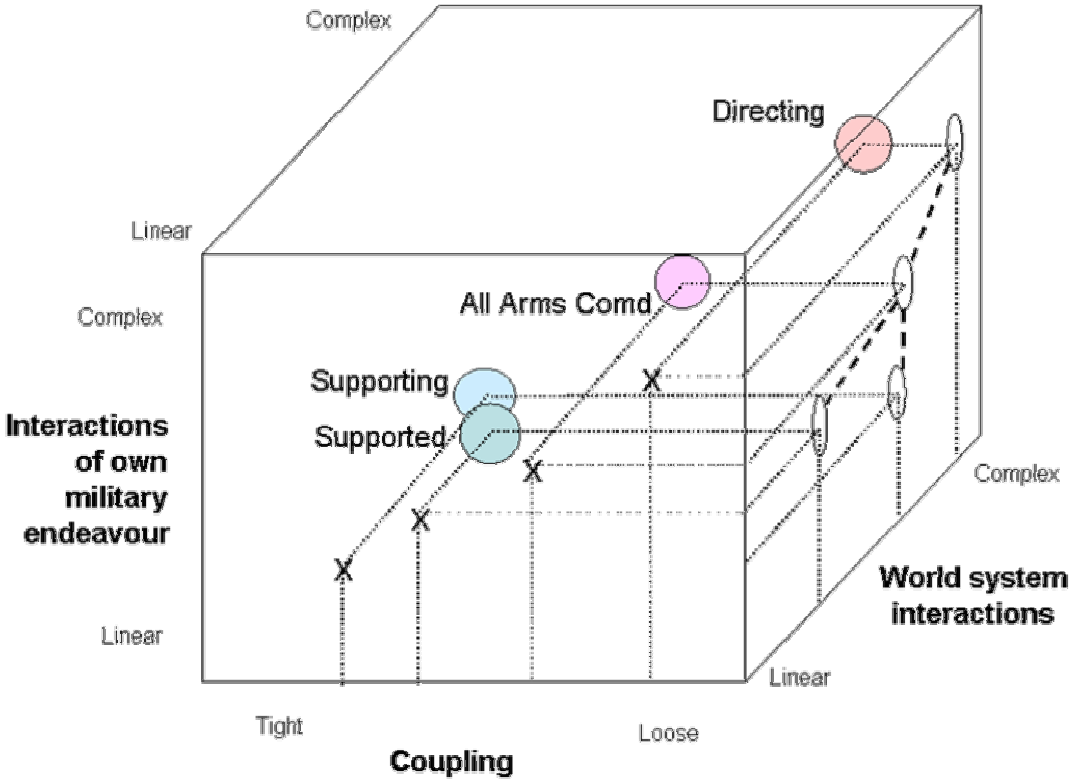

Figure 13: Pattern of locations in the command space for the command chain

[8] Robustness: the degree to which our people and capabilities will remain effective in arduous conditions, particularly in close combat with an adversary, but also ***the ability to conduct different missions with the same capability'*** (our emphasis). HLOC, JDCC, March 2004, paragraph 303.

EARLY RESULTS OF COMBAT SIMULATIONS

Early results of HiLOCA[9] simulations show the combat effects (in terms of operational tempo, combat losses, logistics tempo, etc) of increased information sharing against varying the C2 process organisations, parameterised using the levels of NCW maturity[10].

These early results show that provision of technological networks for data and information sharing without appropriate changes to the C2 process organisation produces little or no improvement in operational effects. Hopefully we will be able to present the results of the simulations as an ICCRTS poster.

CONCLUSIONS

What are the unavoidable functional impacts of effects-based, network-centric operations (EBNCO) on command and control (C2)? In other words, given the current programs to increase the degree of information sharing, what C2 mechanisms, organisation structures and new ways of working will be necessary to enable military forces to function in future conflict operations?

Working with Perrow's quadrants allows us to overlay mission-specific, cost-benefit contours on the command space that help to analyse and measure value of networking in terms of quality of service and cost of various C2 and force package options.

These values relate to the benefits and costs of providing the capability from 'organic' assets. The 'technical' quality of service measure ($Value_1$) needs to be modified by a representation of the clarity of lines of authority, responsibility and accountability ($Value_2$). The final composite $Value_3$ defines the continuity and navigability of the command space, impacting on C2 agility in respect of moving from one C2 style to another. In order to assess the functional impacts of NCOs we need to gain a full appreciation of functional participation and the associated changes in value that may result in a potentially non-linear, even discontinuous, future C2 space.

This paper only begins to open a door on the problem of determining the Way of Command in future effects-based, network-centric operations where real-world constraints of all kinds will demand that C2 organisations attain a high "fitness" level. It is clear that the Way of Command problem needs to be approached from both sides at the same time such that ENDS are defined in full acknowledgement of the nature of the MEANS and also the nature of the activities and interactions necessary to carry out the operation and also all of the infrastructure constraints. The combination provides an outline cost-benefit landscape against which the various (necessarily nested) C2 organisations will be "valued". We cannot at this stage specify methods to arrive at C2 structural solutions and, in any case, we need to remember that the overall aim, after all, is to try to remain as organisationally agile as possible.

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[9] S Richardson & L Dodd, 'Investigation of Impact of Knowledge of Own Forces on Operational Effectiveness', QinetiQ TR050909, March 2005. (HiLOCA is a UK combat model that simulates land forces with explicit representation of information-driven command and control processes and C2 organisations.)

[10] D Alberts, R Hayes, 'Power to the Edge', CCRP publications, Figure 13, Page 109.

Functional Impacts of NCO on Future C2

Perrow's Quadrants: coupling, interaction and projection

Lorraine Dodd, Lt Col Merfyn Lloyd, Geoff Markham

14 June 2005

Paper #188
10 ICCRTS
McLean, Virginia
June 2005

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Edge Concepts

- Run-time and acquisition time
  - Paper 107, Track 12 A. Alston
- Command Leadership and command styles
  - Paper 298, Track 9 K. Stewart
- Organising for response to external stimuli
  - Paper 188, Track 12 L. Dodd
- Influencing and exploiting the properties of complex adaptive systems
  - Paper 115, Track 12 P. Beautement
- Capability architectures
  - Paper 232, Track 12 M. Lloyd

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What we are trying to understand

- Nature of the challenge space
  - unpredictability
  - need for precision and accuracy
- How do structures and infrastructures then need to be configured (and re-configured) so that they are as fit as can be given the nature of the challenge space
- Use of Perrow's work to explore complexity and coupling

Changes in environment

- Our concern is military structures for deployment and employment of force in response to:
  - On-going actions by an opposing force
  - Events that cause damage
  - Anticipation of undesirable situations
  - Need to improve power position (to increase options-space)
- The structures must balance ENDS, MEANS and WAYS so that the WAY that the structures adapt allows the force to achieve the ENDS within the MEANS.

HOWEVER….
The structural design principles for EOs should address the degrees of freedom of WAYS and MEANS given that the purpose of the EO is to be able to effect change in any way to its advantage in the context of any of the above four changes in the environment.

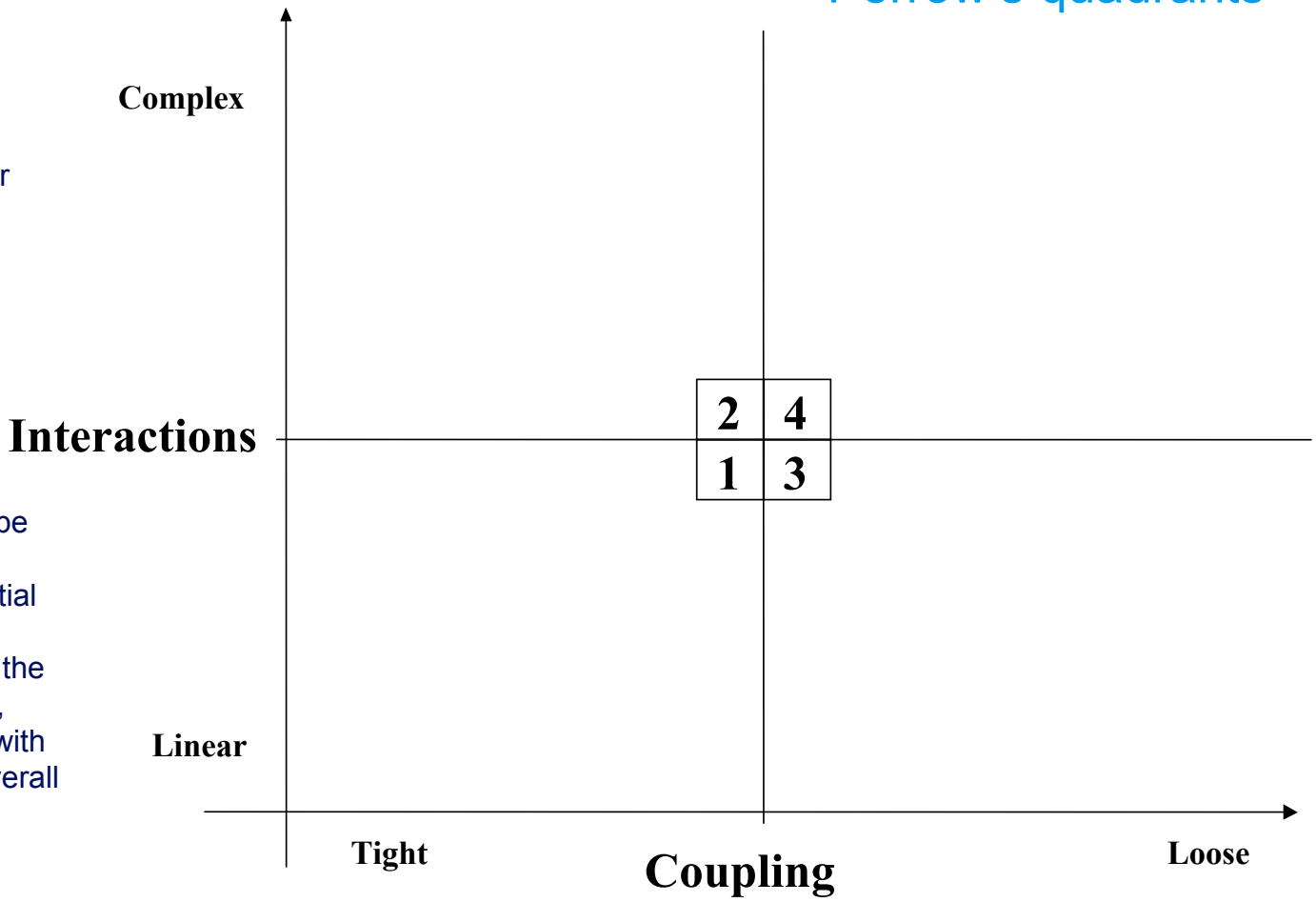
Disturbance and system damage

- The degree and nature of disturbance is directly related to what we define as “the system”
- In Perrow’s framework, it is the character of the system – its intrinsic organisation- that CAUSES damage; although the stimulus mostly originates from outside the system.
- What are the critical aspects of the system that if disturbed would constitute system damage?
- What are the restraining and constraining features of the system that would affect recovery responses?

Then we can define (in terms of “system impact”) what is meant by
•An event
•An incident
•An accident

Perrow's quadrants

Complex interactions are less predictable. Breakdowns within one or more units and or subsystems may occur because of unplanned or unforeseen interactions and "knock-on" effects.



Linear interactions describe highly structured systems which are logical, sequential bounded and planned. If damage to a part occurs, the problem can be identified, contained and corrected with little disturbance to the overall system.

Tight coupling is characterised by centralisation and rigidity, tightly-specified tolerances – any change causes ramifications throughout the system.

Loose coupling is characterised by decentralised operations, flexible control mechanisms

Charles Perrow "Normal Accidents: living with high-risk technologies, Princeton 1999
Chapter 3: Complexity, coupling and catastrophe

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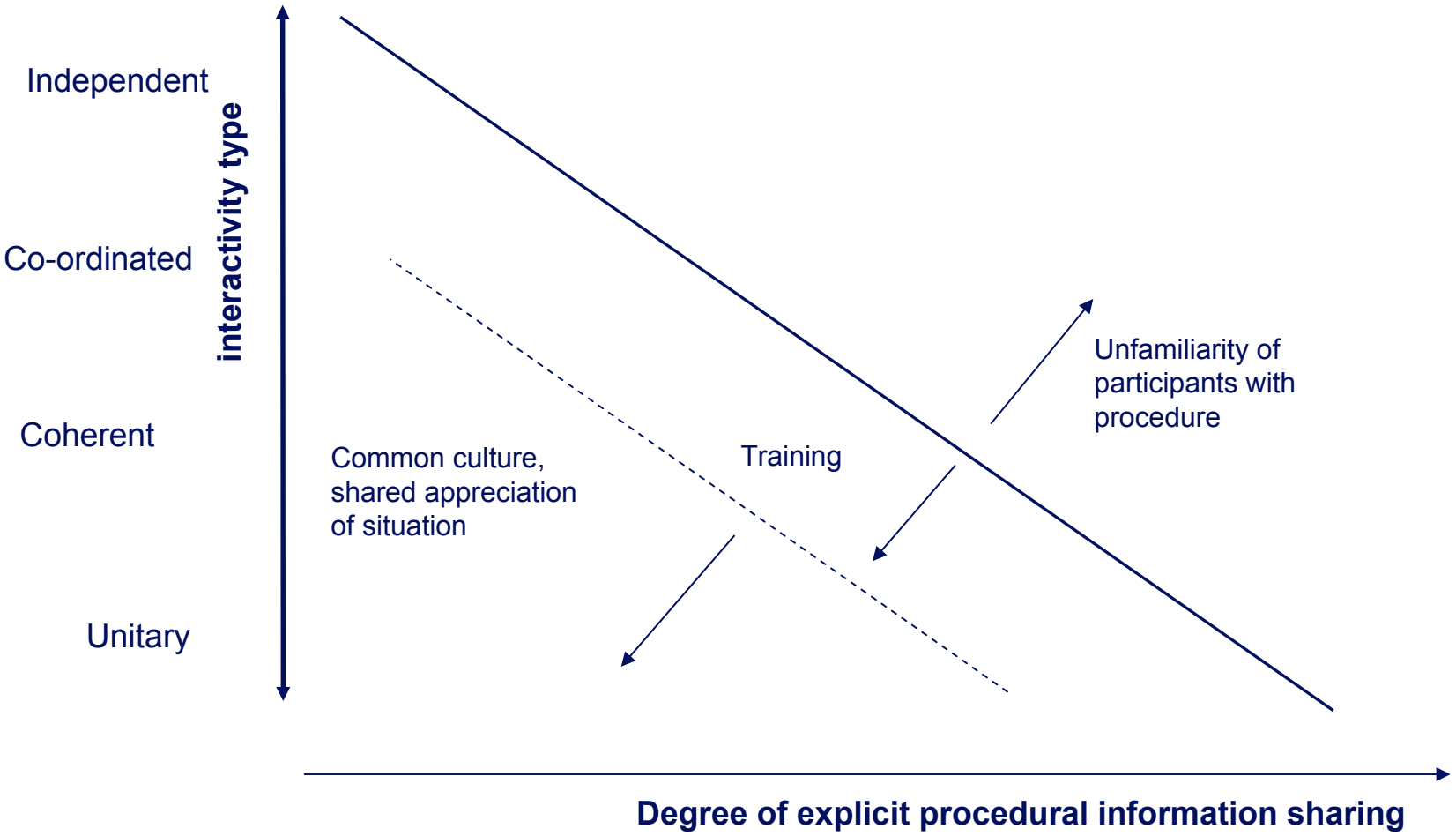
Interactions and coupling

- The main influence of the “interactions axis” is in one’s ability to project forward in time; in particular, unintended and unanticipated consequences due to interactions that are difficult to “linearize-out” because of inter-dependencies. “Visibility” of interactions (sensors at key points) may help to limit undesirable system behaviours.
- The “coupling axis” relates to system criticality due to constraining factors. It involves application of the critical aspects to assess (i.e. is this OK or not?) feedback from the system as it goes about its purposeful function. It is about tolerances, buffering and tightness.
- The system/sub-system boundaries should be set to try to limit expected damage with respect to the range of purposes and the repertoire of controlled responses for recovery from failure.

Note though that more boundaries means more interfaces to manage

Four types of interactivity

- **Independent**: Separate and discrete activities – i.e. concurrent activities without direct interdependencies (but usually both acting towards the greater good)
- **Co-ordinated**: Serial interdependency linked through shared artefacts or through a common metric space.
- **Coherent**: Acting coherently, in concert with mutual orientation in the same part of the environment and sharing the same feedback.
- **Unitary**: Behaving as if they were a single entity for some period of time (reduced degrees of individual freedom are traded off against being able to wield greater collective potential).


Independent
Co-ordinated
Coherent
Unitary
interactivity type
Unfamiliarity of participants with procedure
Training
Common culture, shared appreciation of situation
Degree of explicit procedural information sharing

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Types of feed-back & feed-forward

- Internal feed-back (proprioception and operative monitoring)
- Internal feed-forward (adjustment to internal WAYS, ENDS and MEANS – and structures to reduce discomfort)
- External feed-back (intents from external commands, ROEs, SOPs, Intel)
- External feed-forward (requests for resources, extra support, changes to decision authorities and planning process, directives to sub-ordinates)

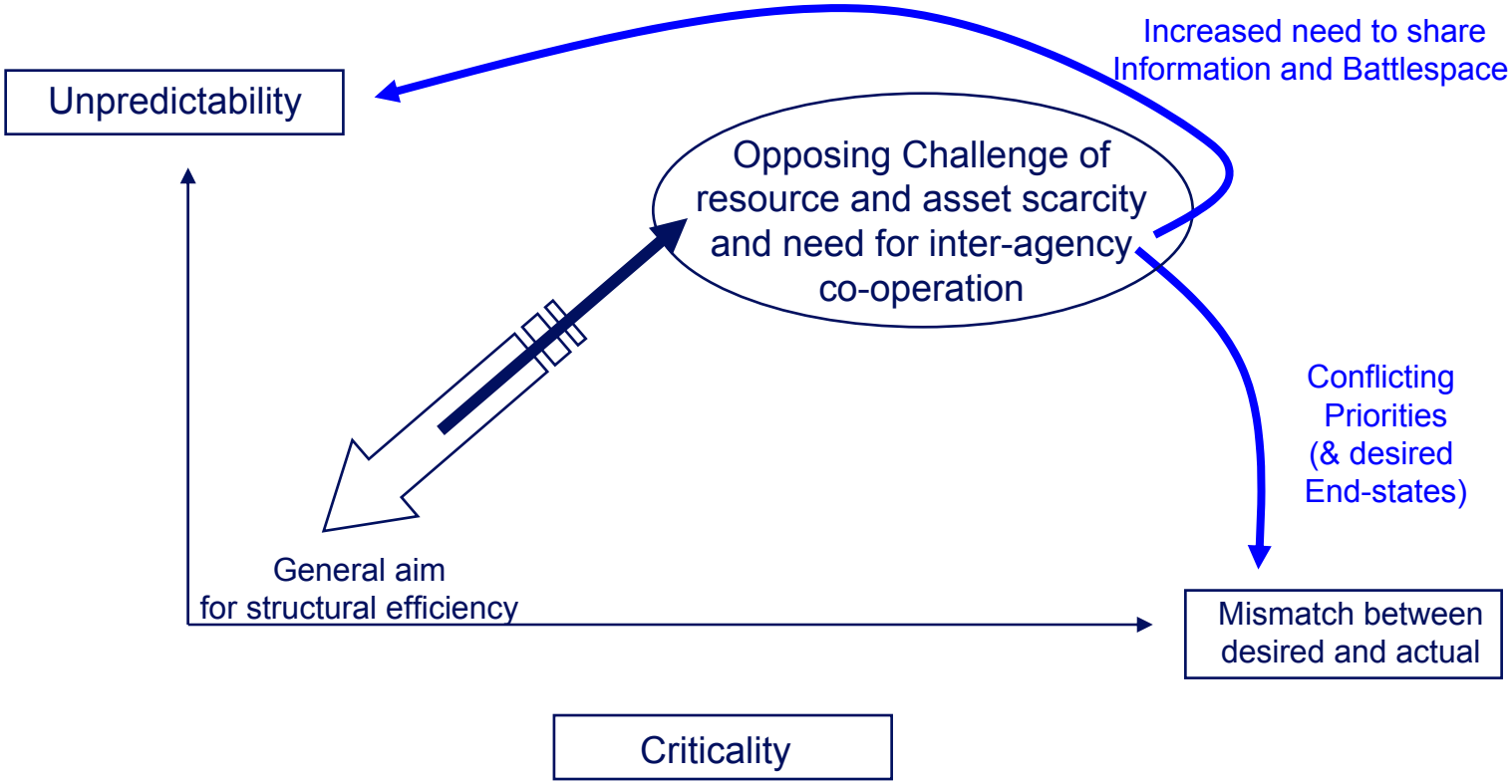
Note that feed-back generally is trying to reduce confusion & uncertainty to allow anticipation. Feed-forward is making adjustments to reduce discomfort and keep options-space as open as possible.

What determines connection strength?

- The main driver is the degree of interdependency (need and willingness to inter-depend).
- The main “transaction-cost cutter” is the infrastructure which includes the degree of out-sourcing (see paper)
- The nature of the operational activities (the roles and the relationships of the operating units) in conjunction with the interdependencies and the infrastructures then determines the nature of the interactions.
- The strengths of the connections is then a changing function of the relative dynamics of the activities (in terms of their feed-back and feed-forward).

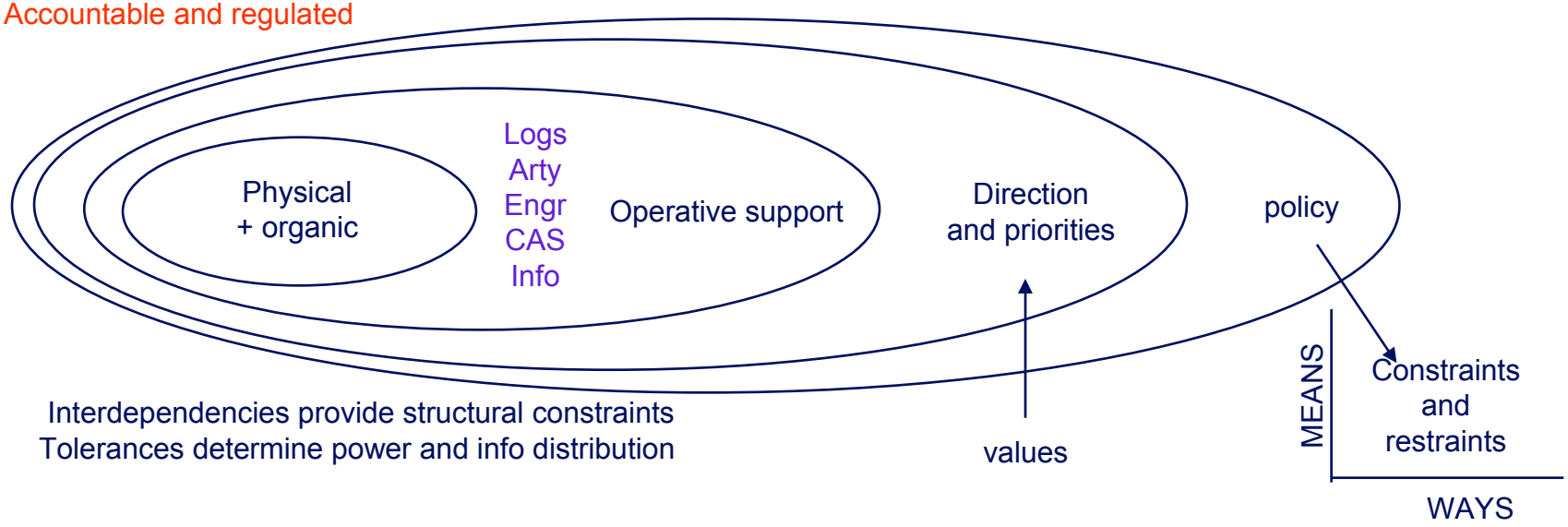
Two structural drivers

C2 decisions essentially have two major driving components: consequences and their likelihood
C2 structures should adapt to allow C2 decision-making to balance these two components
Scarcity increases need for interdependence and number of interactions

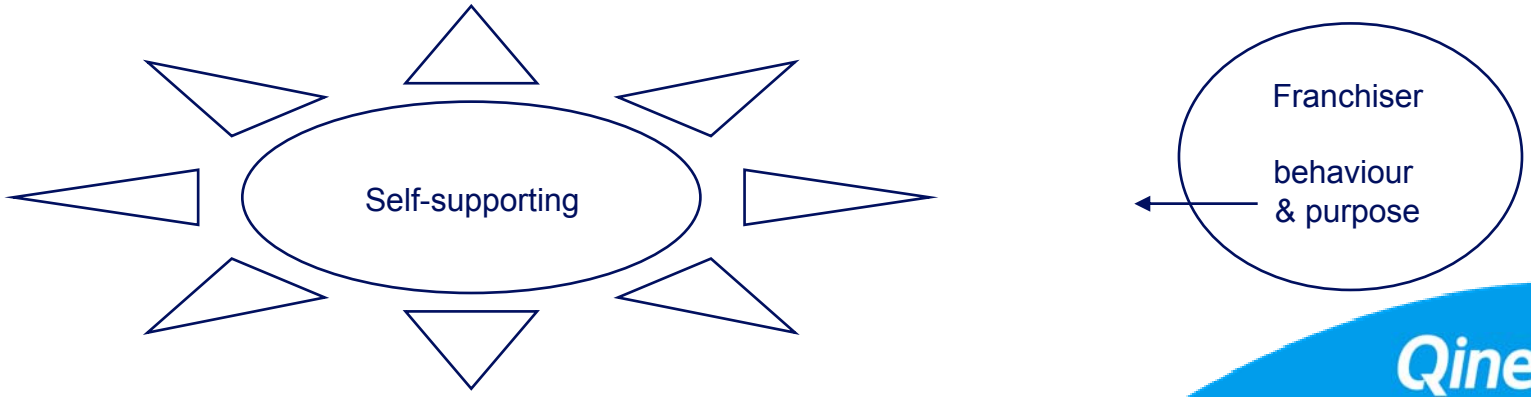


Two structural extremes

Accountable and regulated



Purposeful and self-regulated



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Summary

The nature of the point at which the stimulus is sensed (i.e. the level of the operating unit and its connectivity - hence propagation of the stimulus) begins to define the structural requirements for the responsive action.

The response will be naturally constrained by MEANS available and WAYS will be restrained by policy (RoE's) but the organisation should maintain adequate degrees of freedom to place responsibility for action with those who have authority over the MEANS and Intelligence.

However, the need for accountability and levels of competence, experience and trust will play a major part in the allocation of decision responsibility and in setting the depth of supervision.

Questions?

Lorraine Dodd

Tel: 44 (0)1684 896135

Email: ldodd@QinetiQ.com

QinetiQ Ltd.,
Alan Turing Building,
Malvern Technology Park,
St Andrews Road,
Malvern, Worcs. WR14 3PS.
UK.

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